

The bow shock-wave impingement on the wing leading edge was also investigated. The location of impingement was a function of free-stream Mach number and vehicle angle of attack; no bow shock-wave impingement was seen on the rudder leading edge. A detailed grid sensitivity study was undertaken

to establish an acceptable level of grid independence of the computed solutions.

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Sharp Leading Edges for Hypervelocity Vehicles

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Recent research shows that ultra-high temperature ceramics (UHTCs) may enable sharp leading edges to be used on space vehicles. Sharp leading edges (≤ 1 centimeter) could enable an entire new design space for hypervelocity vehicles with decreased drag, increased cross-range capability, and reduced cost-to-orbit. These factors, combined with results from ground-based testing and analysis, led to the implementation of the first UHTC flight demonstration. The objective of this flight was to validate the nonablating performance of a UHTC "sharp" leading edge by comparing flight data with theorized material performance data.

Implementation of the UHTC flight demonstration was a joint effort by Ames Research Center, Sandia National Laboratories, and the U.S. Air Force. A Minuteman III (MM III) launch/reentry opportunity was secured.

Ames designed a UHTC nosetip that sharpened the conventional Mk12A nose from a radius of 0.861 inch to 0.141 inch, as shown on the SHARP reentry vehicle, at the left in the figure. A microminiature thermocouple sensor was designed to measure the temperature within the nosetip. These articles were successfully fabricated, tested in the Ames arc-jet facility, and taken to Sandia National Laboratories for environmental testing. The reentry vehicle (RV) was flown to Vandenberg Air Force Base (VAFB) for further testing and integration with the MM III.

SHARP-B01 was launched from VAFB at 1:27 A.M., May 21, 1997. Once exoatmospheric, SHARP-B01 was deployed and entered Earth's

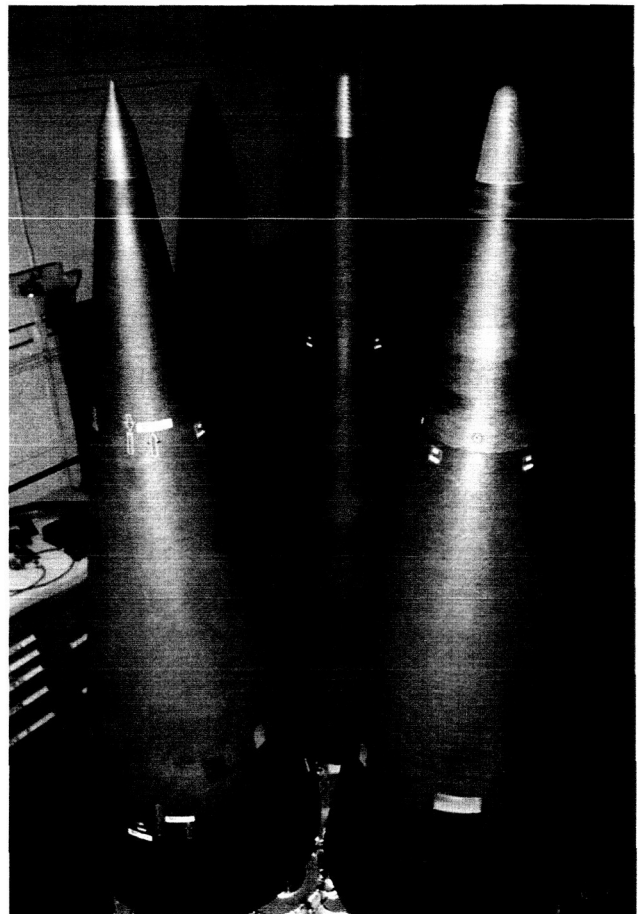


Fig. 1. The 0.141-inch radius nosetip SHARP-B01 reentry vehicle shown with standard Mk12A reentry vehicles.

atmosphere at velocities up to 22,700 feet per second. The nosetip sensor indicated that initial ablation occurred near an altitude of 191,000 feet at a velocity of 22,700 feet per second. Before and during nosetip ablation, SHARP-B01 dynamics were nominal.

These flight results validate the preflight expectations of the UHTC nosetip performance. Arc-jet tests, integrated design tools, and now flight data all

demonstrate the material's ability to operate at a temperature of 5100°F before it degrades.

The results of this flight demonstration of sharp leading edges have generated great interest in the aerospace industry.

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Arc-Jet Flow Characterization

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Arc-jet facilities have been used extensively to evaluate materials for use in the thermal protection of aerospace vehicles, from Apollo spacecraft and the shuttle to the X-33 and the X-34. Although arc-jet tests are indicative of how well a material will perform in extreme aerothermal heating environments, it has not been possible to directly relate arc-jet test results to flight applications. The main obstacle has been an inability to determine the total enthalpy of the nonequilibrium arc-jet flow, and its distribution among kinetic, thermal, and chemical modes. The objective of this work is to develop diagnostic techniques to determine these quantities, thereby improving our understanding of the relationship between arc-jet test and flight environments.

As part of this effort, a laser-spectroscopic instrument has been developed to characterize the flow environment by measuring the free-stream enthalpy in large-scale arc-jet facilities. This approach involves making flow-property measurements using two-photon laser-induced fluorescence (LIF) of atomic nitrogen; it was recently demonstrated in a series of tests conducted in the Aerodynamic Heating Facility (AHF). The flow properties, which include velocity, translational temperature, and species concentration, were measured simultaneously over a range of facility operating conditions. When combined with facility measurements of mass flux and pitot pressure, an analysis of the flow properties obtained using the two-photon LIF

technique yields the kinetic, thermal, and chemical enthalpy components of the free-stream flow directly; the total flow enthalpy is calculated from the sum.

Example two-photon LIF excitation spectra from atomic nitrogen obtained from the arc-jet flow and from a flow reactor, which is used to calibrate the arc-jet measurements, are presented in the first figure as a function of the dye fundamental wavelength.

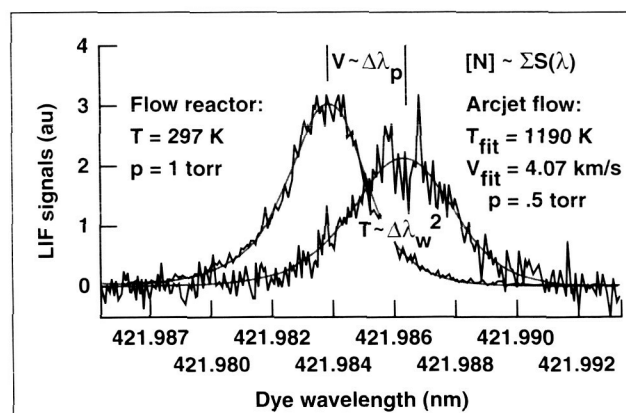


Fig. 1. Excitation spectra from two-photon LIF of atomic nitrogen from the arc-jet flow and from the flow reactor. The narrower spectrum is from the room-temperature, low-pressure flow reactor; the broader spectrum is from the higher-temperature, lower-pressure, nitrogen/argon arc-jet flow.